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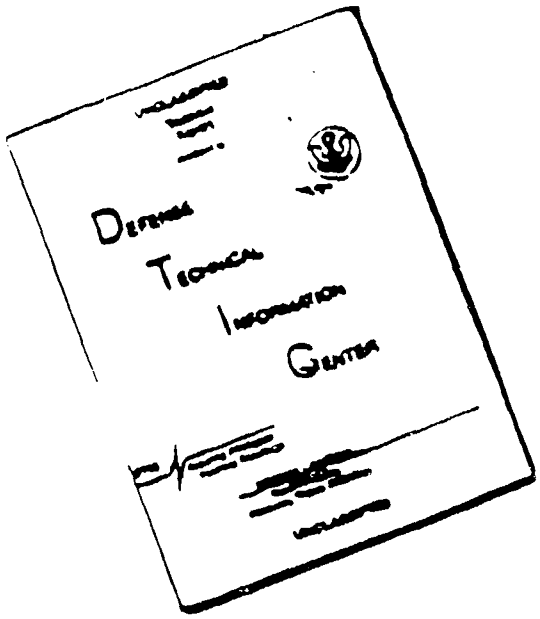

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TECH. NOTE
RAD.702

SECRET - DISCREET

ROYAL AIRCRAFT ESTABLISHMENT

TECHNICAL NOTE No: RAD.702

INFRA-RED DECOYS

by

T.S.MOSS, Ph.D., D.R.BROWN, B.Sc. and T.D.F.HAWKINS

SEPTEMBER, 1957

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ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

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SUMMARY

The general requirements for an infra-red decoy are assessed.

Measurements are described of the emission of standard R.A.F. flares, and experimental A.R.D.E. flares. For the latter it is estimated that a decoy weighing ½ lb will give four times the radiation from a V-bomber in the PbS band for 6 seconds, and ¾ lb will give four times the gas radiation in the PbTe band.

Selectively emitting materials - namely Cordites - have been investigated with promising results. Of this material a "PbS" decoy would weigh ½ lb, and a "PbTe" decoy 1/3 lb. Cordite itself however is probably unsatisfactory at high altitudes.

At the suggested discharge rate, protection for three periods of ten minutes would be given by 180 decoys, while protection for a full three hours would need about 1,000 decoys.

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1 Introduction

Decoys are one of the possible countermeasures to infra-red homing missiles and their use is considered particularly for protection of the V-class bombers against air-to-air missiles of the Blue Jay type.

The main type of decoy considered is a burning flare which is dropped or ejected from the bomber when under attack, the radiation from the flare being such that in the operative waveband of the detector it is several times as large as that from the bomber itself. (It has been decided at R.A.E. tentatively, to use a ratio of 4:1 in assessments (see Appendix I).) The homing head of the missile should then lock-on to the decoy, so that the missile is deflected away as the decoy separates from the bomber.

The chief disadvantage of the decoy countermeasure technique is that it is an intermittent form of countermeasure which necessitates information to decide when to use it, and since the homing missiles are passive systems there can be no direct warning of attack. For this reason permanent I.R. countermeasures are to be preferred whenever feasible - i.e. radiation suppression in the case of the V-bombers.

When combating lead sulphide homing systems it seems feasible to reduce the radiation from the jet engines to a level where our own Blue Jay homing missile would have inadequate detection range. However, in the more distant future it is likely that we shall have to combat missiles with lead telluride detectors which detect not only the radiation from the hot metal of the jet engines, but also from the hot gases themselves. As there appears to be little hope of cooling the exhaust gases*, it is thought at present that the most promising countermeasure to the lead telluride homing missile is a suitable decoy.

Also, since there is a steady development in the sensitivity of PbS detection systems and in the power (and hence radiation level) of jet engines, there is still some interest in the use of decoys in this field. Decoys also may be needed as fuze countermeasures, or in cases where I.R. suppression is impracticable. It may be desirable to use a combination of partial I.R. suppression and a corresponding decoy.

Apparently the U.S. are already designing flare ejectors for B.47 and B.52 bombers. These ejectors (designated AN/ALE-14) each have 51 decoys in a space of about ½ cubic foot. Each 200 gm pellet gives an emission of 1,000 watts/ster. in the PbS band, for 6 seconds.

This report assesses the sizes of decoys needed for the PbS and PbTe wavebands, and describes measurements made on various possible flare materials. It is hoped that it will provide a basis for discussions on the operational suitability of flares as infra-red countermeasures and hence the nature of future development work.

2 Assessment of Decoy Emission Required

In the PbS waveband our measurements show that the emission of a V-bomber with four large engines at maximum cruise condition at an angle 20° from astern is ~400 watts/ster. To give four times this radiation, the required isotropic emission from the flare will be 20,000 watts. Taking a desirable burning time of 6 seconds (see Appendix I) we therefore need an emission of 120,000 joules.

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*Temporary cooling of the exhaust gases by cutting the engines is possible and may be an alternative countermeasure.

For the PbTe band engine data is not so comprehensive. However, for a Sapphire engine at maximum power radiation on the beam from the exhaust gases alone of 37 watts/ster. has been observed at R.A.E. For a Conway RC07 operating at maximum cruise condition the beam emission has been found to be 60 watts/ster. when using a 10' 6" jet pipe - i.e. for a condition when there is little mixing of the exhaust and by-pass gas streams. For a large straight jet engine the emission will be greater than this. As a representative figure we will take the beam radiation (i.e. gas radiation only) to be 80 watts/ster. per engine for maximum cruise conditions. Thus to combat such gas radiation from four engines with the same 4:1 safety factor and burning time we need for the PbTe band ~100,000 joules. If in addition in the PbTe band there is radiation from hot metal (i.e. stern attacks) the required decoy signal will be increased. For straight jet engines the signal required will be nine times the above, while for engines suppressed to 280°C the metal emission should be 120 watts/ster. per engine so that to combat the total emission will then need 2½ times the decoy size, or 250,000 joules.

3 Details of Field Measurements

Measurements were made normally at ranges of 200 yards or more.

Both PbS and PbTe detector systems used 3" diameter optics and 800c/s chopping. These systems were calibrated in situ against black body radiators. The PbS system used a germanium filter and had an effective bandwidth of 1.9-2.6μ, the PbTe system was fitted with a PbS filter giving an effective bandwidth of 3.2-5.1μ. These detector systems were the same ones which had been used to determine the radiation from jet engines quoted in section 2.

From the signal levels obtained the total radiation in the above wavebands can be calculated.

4 Experimental Results for Conventional Pyrotechnic Materials

4.1 Emission Measurements

Several types of standard R.A.F. flares were measured, including

(i) 3 lb, 1.6" diameter Target Indicator Candle

(ii) 20 lb, 4" Aircraft Anti-submarine Flare

(iii) ½ lb, 1.7" Aircraft Illuminator Flare No. 1, Mk. 1.

The last of these was much more efficient than the others and detailed results will be given only for this type.

This flare consists of 3 stars. Each star has 75 gms of pyrotechnic material (SR.580) with dimensions 2.6" long, 1.5" diameter. It burns for 3 seconds after 1½ seconds delay. The composition is given in Appendix II.

The average measured emissions were:

PbS (1.9-2.6μ) band, 700 watts/ster. } for one star
PbTe (3.2-5.1μ) band, 460 watts/ster. }

About three times this value was obtained when all three stars were fired together, provided the stars remained in the field of view of the detector.

Work on the development of flare materials has now started at A.R.D.E., Langhurst, and two types of specimens have been supplied to us for testing.

One type contained SR.580 composition as in the flare described above. These samples contained 75 gms of composition in cardboard cases 1.4 inches diameter and burnt for 6 seconds.

The average emission at 300 yards range was

PbS band	270 watts/ster.
PbTe band	180 watts/ster.

Assuming the emission to be isotropic and allowing for the burning time of the flares we can derive the following figures for the specific emission:

TABLE I

Emission of SR.580 Samples

PbS band	270 joules/gm.
PbTe band	130 joules/gm.

Similar emission values to those in Table I would be obtained for the 1.7" Aircraft Flares if the 3 nominal second stars were assumed to burn at full power for 2.3 seconds.

The other composition supplied by A.R.D.E. was SR.107*. These specimens were of 100 gms total weight, 1.4 inches diameter, and filled with 75 gms of SR.107 material. They burned effectively for 13 to 14 seconds. The average measured emission at 300 yards range is given in Table II.

TABLE II

Emission of SR.107 Samples

PbS band	330 watts/ster. or 710 joules/gm.
PbTe band	180 watts/ster. or 390 joules/gm.

It will be seen that these experimental flares give two to three times as much I.R. emission as SR.580 used in the standard Aircraft Illuminator Flare. From the ratio of the emissions in the two wavebands (see Figure 1) after additional allowance for atmospheric absorption (Section 4.2), the effective black body temperature of the burning flare is found to be about 2,000°C. It should be noted that this method of determining temperature is only valid when no selective emission occurs, as would be the case if hot CO_2 or water vapour resulted from combustion. This temperature agrees well with the figure of 2,100°C determined by A.R.D.E. by visual pyrometry (A.R.D.E. Branch Memo. 34/2/57). For a temperature of 2,000°C the percentage of the total radiation which falls in the wanted waveband is:

PbS band	19%
PbTe band	12%

Using the figures for the required emission given in Table II, the amount of SR.107 material required to give an emission of four times that

*See Appendix II for composition

of a V-bomber for 6 seconds for the PbS band will be 225 gms or ½ lb*. Similarly, for the PbTe band, the measured values at 300 yards show that to give four times the gas radiation of the V-bomber will require roughly ¾ lb*.

4.2 Atmospheric Transmission Measurements

Measurements of the atmospheric transmission at ground level in the PbS and PbTe bands have been carried out on samples of SR.107 and SR.580. The results are given in Figures 2, 3, 4 and 5 showing the measured flare radiation for ranges up to about 1 mile. These results apply only at ground level. At high altitudes, with little water vapour absorption, no appreciable attenuation would be expected in the PbS band provided glass optics were employed in the detector system to remove the effects of CO_2 absorption at 2.7μ. However, as the measured absorption at ground level is in fact small, the increase in signal at high altitude will be slight.

In the PbTe region at ground level both water vapour and CO_2 absorption bands are present. In fact the water vapour absorption at both edges of the band must be quite appreciable to account for the relatively steep attenuation observed. At high altitudes only CO_2 absorption would remain and the infra-red transmission would be considerably increased. Figure 5 indicates that at zero range (i.e. no absorption) the signal would be about 50% greater so that for high altitude operation where absorption may be unimportant the weight of an SR.107 decoy for the PbTe band could be reduced to about ½ lb*.

5 Selectively Emitting Materials

It seemed that a considerable gain in radiant efficiency would be obtained if a flare material which emitted selectively in the spectral region required could be used. In particular it seemed promising to investigate decoys which gave CO_2 emission for the PbTe band, and to a lesser extent to have H_2O emission in both bands. Both these requirements can be met by burning hydro-carbons and as a convenient form of material carrying its own oxygen we used Cordite of various types.

5.1 Spectral distribution of Cordite Radiation

In order to measure the spectral distribution of radiation small samples of Cordite were burned at a fixed position near the entrance slit of the spectrometer. Three samples were burned for each wavelength setting of the spectrometer so that repeatability could be checked.

The spectrometer and detection system were then calibrated over the same waveband by use of a black body radiator, so that the true spectral emission could be found.

The results for type SC are shown in Figure 6. It will be seen that there are marked emission bands in the region of 2.8μ and 4.5μ. All types of Cordite gave similar results in the PbTe band - in the PbS band the emission of type CSC was about twice that of type SC.

5.2 Total Emission of Cordite in PbS and PbTe Wavebands

Measurements of the emission of weighed quantities of Cordite were made using the PbS and PbTe detecting systems. Results for the best type (CSC) are shown in Table III. The values are an average of about 20 results at ranges between 100 and 300 yards.

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*Including an allowance of 25% of total weight for a suitable cardboard case.

TABLE III

Emission of Cordite

	PbS band	PbTe band	
Type CSC (Average of 20)	36 watts/ster.	41 watts/ster.	8 seconds for 4.7 gm.

From the above results we find the specific emission for measuring ranges ~ 200 yards to be:-

PbS band 780 joules/gm.

PbTe band 880 joules/gm.

Comparison with Table II shows that the Cordite is more than twice as good as the SR.107 composition in the PbTe band, and is somewhat better in the PbS band. For six second decoys the required weights of Cordite would be ½ lb for the PbS band and 1/3 lb for the PbTe band*.

The reaction energy of Cordite is quoted as 4,400 joules/gm. Hence from the above figures 20% of the available energy is being radiated in the PbTe band and 17% in the PbS band - i.e. 37% of the radiation is useful. From Figure 6 it is clear that there is considerable radiation between the two useful bands, i.e. 2.6-3.2μ, which may be of value at high altitudes where water vapour absorption is low.

5.3 Atmospheric Absorption of Cordite Radiation

Attempts to measure the atmospheric absorption of Cordite radiation at ground level have not been very satisfactory. This is mainly due to the erratic burning of the samples in the open. However, an average of many measurements of radiation at ranges up to 1,000 yards indicate a fairly rapid fall in radiation in the PbTe band. The fall in radiation with range is greater than that experienced by a jet engine plume where a fall to ½ occurs in 800 yards - which is somewhat surprising since CO_2 in the jet plume would be at a lower temperature than the Cordite flame. A possible explanation may be that water vapour is also causing appreciable absorption since the Cordite emission extends to the water vapour bands around 3 and 5 microns.

The results indicate that at zero range (i.e. no absorption) the emission would be about twice that measured at ranges ~ 200 yards and quoted in Table III. Thus at high altitudes where absorption will be small it might be possible to reduce the weight of the Cordite decoy to 1/6 lb for use in the PbTe band.

6 Conclusions

The SR.107 composition developed by A.R.D.E. is shown to be a useful infra-red decoy material, and it is strongly recommended that these workers should be encouraged to continue their development of such pyrotechnic materials.

The high specific emission of Cordite makes it a promising infra-red decoy material. In its normal form however it is extremely pressure sensitive and will not burn at all well at low ambient pressures (see Appendix III). It may be possible to overcome this defect by partially confining the Cordite or by mixing it with a magnesium based

*Including an allowance of 25% of total weight for a suitable cardboard case.

pyrotechnic material, or possibly by using some of the other self oxidizing hydrocarbons which would be expected to have similar infra-red properties. It is recommended that A.R.D.E. should be asked to investigate such selective emitting materials, including Kul F, which is reported from America to be a very efficient decoy material with a low burning temperature ~1,700°C.

At the discharge rate suggested in Appendix I, namely every 10 seconds, protection for three periods of 10 minutes would be given by 180 decoys, and protection for a full three hours by about 1,000 decoys.

The degree of protection expected from ½ lb decoys for various conditions is summarized in terms of the number of engines which would give the same signal, in Table IV.

Attached:

Table IV
Appendices I - III
Diags Rad/T.3806-3813
Detachable Abstract Cards

TABLE IV

Equivalent Emission of ½ lb Flares in terms of Engine Radiation

Decoy Material	Waveband	Absorption assumed	Type of Engine Radiation			Equivalent number of engines
			Gas only	Total	Total, suppressed to 280°C	
SR.107	PbS	Not relevant		✓		16
		Not relevant			✓	300
SR.107	PbTe	200 yds at sea level	✓			11
		None	✓			16
		None		✓		2½
		None			✓	8
Cordite	PbS	Not relevant		✓		16
		Not relevant			✓	300
Cordite	PbTe	200 yds at sea level	✓			22
		None	✓			44
		None		✓		5
		None			✓	19

N.B. At long ranges target is four engines. At ranges below 1,500 yards target is only two engines.

APPENDIX I

Missile and Decoy Characteristics

Taking Blue Jay as a reference for the homing missile, the instantaneous field of view and the number of engines of a V-bomber seen simultaneously at various ranges are given in Table V.

TABLE V

Missile Field of View

Blue Jay instantaneous Field of View (0.2°)

Range	Field of View	No. of Engines
4,000 yards	42 feet	4
3,000 yards	31 feet	4
2,000 yards	21 feet	3
1,000 yards	10 feet	2

Thus at normal launching ranges four engines will be seen, but over the last 1,500 yards of approach not more than two engines will be providing the target signal. In view of this it might be permissible to reduce the decoy emission to twice that of the four engines, with the knowledge that in the closing stages this will be four times the target signal. This would halve the weight of all the decoys quoted in this report.

The field of view for recapture of a target for Blue Jay is ~ ± $1\frac{1}{4}^{\circ}$ - i.e. the decoy must take the homing head at least this far off the target before burning ends or the target will be found again. At the maximum likely launching range of 4,000 yards this corresponds to ± 300 ft. To provide such a separation from the target by falling freely under gravity the decoy will require to burn for over four seconds. On the other hand, if the missile is at 3,000 yards at launch, and the missile head is slaved to the target by radar for example so that it does not follow a decoy before launching, then after $3\frac{1}{2}$ seconds a decoy would have fallen outside the field of view, so that a burning time much longer than this would be wasteful. At optimum burning time of 5 or 6 seconds is indicated by these considerations.

An estimate can be made of the advisable rate of ejection of decoys using the tentative assumptions that the overtaking speed of the missile is 1,000 f/sec. and that it should approach within 1,000 yards without "seeing" a decoy. Now for launching ranges of 2,000-4,000 yards the decoy is always outside the field of view about 4 seconds after ejection, so that the missile could be fired at this time. The intervening distance will be covered in 3-9 seconds and the permissible interval between ejections is thus 7-13 seconds.

For average conditions therefore a 6 second decoy every 10 seconds should be suitable.

At this discharge rate, protection for three periods of 10 minutes would require 180 decoys, while protection for a full three hours would need about 1,000 decoys. In this latter case the overall weight including ejectors would approach 1,000 lbs. This is several times bigger than estimated in A.R.D.E. Branch Memo. S4/2/57 mainly because that report assumed decoys only equivalent to the target and not four times as large, as considered here.

APPENDIX I

Flares

Composition - Percentage by Weight

	Magnesium	Ferric Oxide	Sodium Nitrate	Acaroid Resin
SR.107	35	65	-	-
SR.580	60	-	36	4

The reactions of the above materials are of magnesium burning to magnesium oxide with the oxygen supplied by a convenient solid chemical. The SR.580 was designed to give as much visible radiation as possible and this is achieved by making the flare burn as hot as possible, about 2,700°C with this mixture. A greater proportion of the radiation is emitted in the infra-red if a mixture can be made to burn at a lower temperature such as by making it burn at half the speed. For magnesium to continue burning reliably with most oxidising agents requires a temperature of about 2,100°C - this is attained in SR.107.

The rate of burning of a flare can be changed by altering either the composition or the particle size of the mixture which affects the rate at which oxygen can be made available to the magnesium. At low temperatures the emission may have more spectral selectivity i.e. the radiation may not correspond with that of a black body at some wavelengths. In addition there may be some selective emission from the hot air around the burning flare - particularly CO_2 and H_2O emission - if a sufficient thickness of air is heated. Several attempts have been made to measure the spectral emission, but the results were inconclusive.

APPENDIX III

Cordite

Composition

	Nitrocellulose	Nitroglycerine	Carbamite	D.B.P.
F4/3	55	22	3.5	19.5
CSC	50	35	9	6
SC	49.5	41.5	9	0
HSC	49.5	47	3.5	0

F4/3 Contains 1% Potassium Cryolite; all compositions contain about 0.1% wax or chalk. D.B.P. is di-butyl-phthalate.

Unlike flares, Cordites do not react as a solid-solid phase, but instead as a vapour phase reaction. In consequence the speed of reaction is highly dependent on the pressure of the atmosphere in which they burn. It was found that none of the above Cordites would burn at pressures less than 1/6 atmosphere and none would burn reliably below 1/5 atmosphere.

It may be possible that Cordite compositions can be modified to burn at high altitudes. Since they contain their own oxygen supply their burning is independent of the composition of the atmosphere in which they burn.

FIG. I.

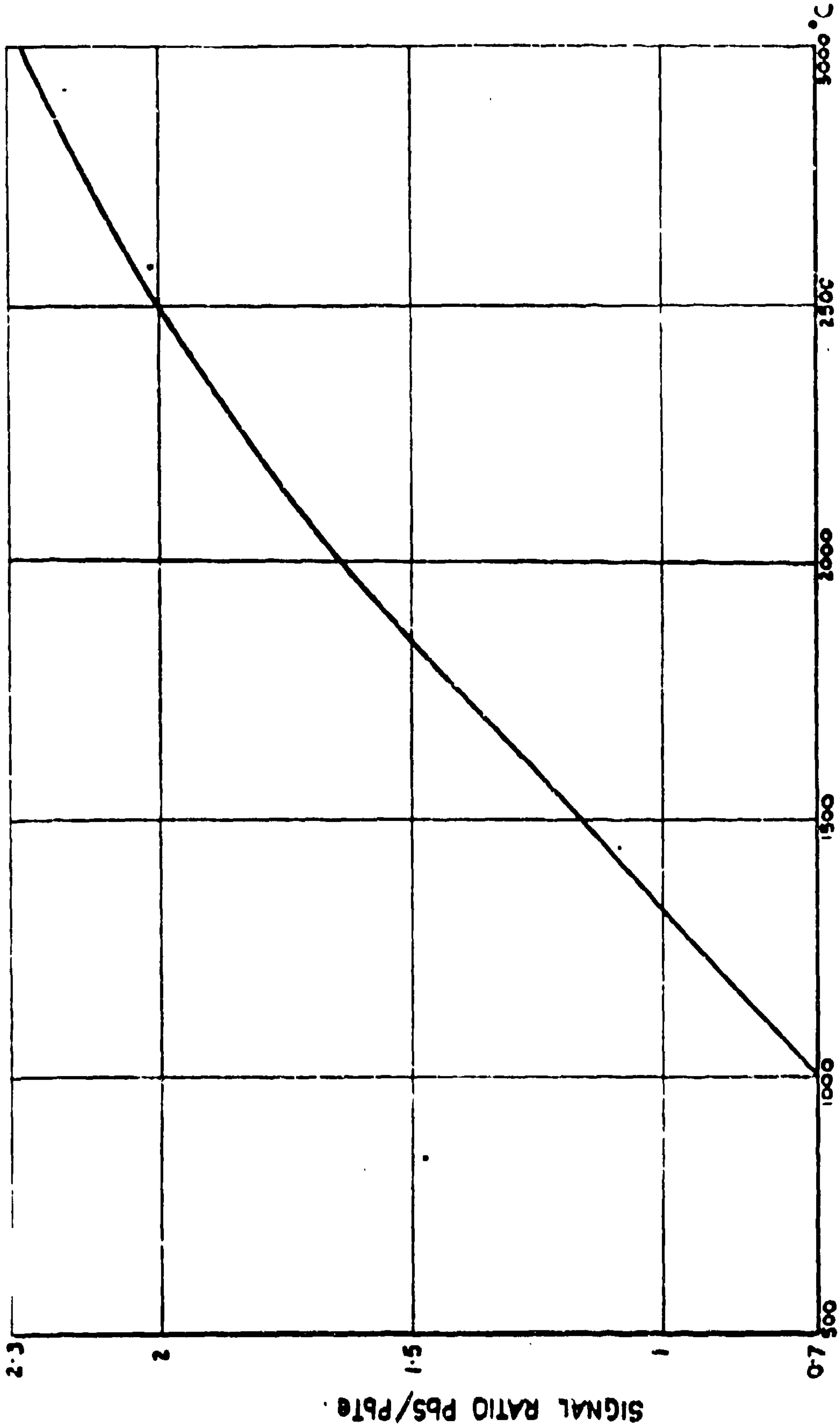

FIG.1 RATIO OF PbS & PbTe SIGNALS FOR VARIOUS BLACK BODY TEMPERATURES.

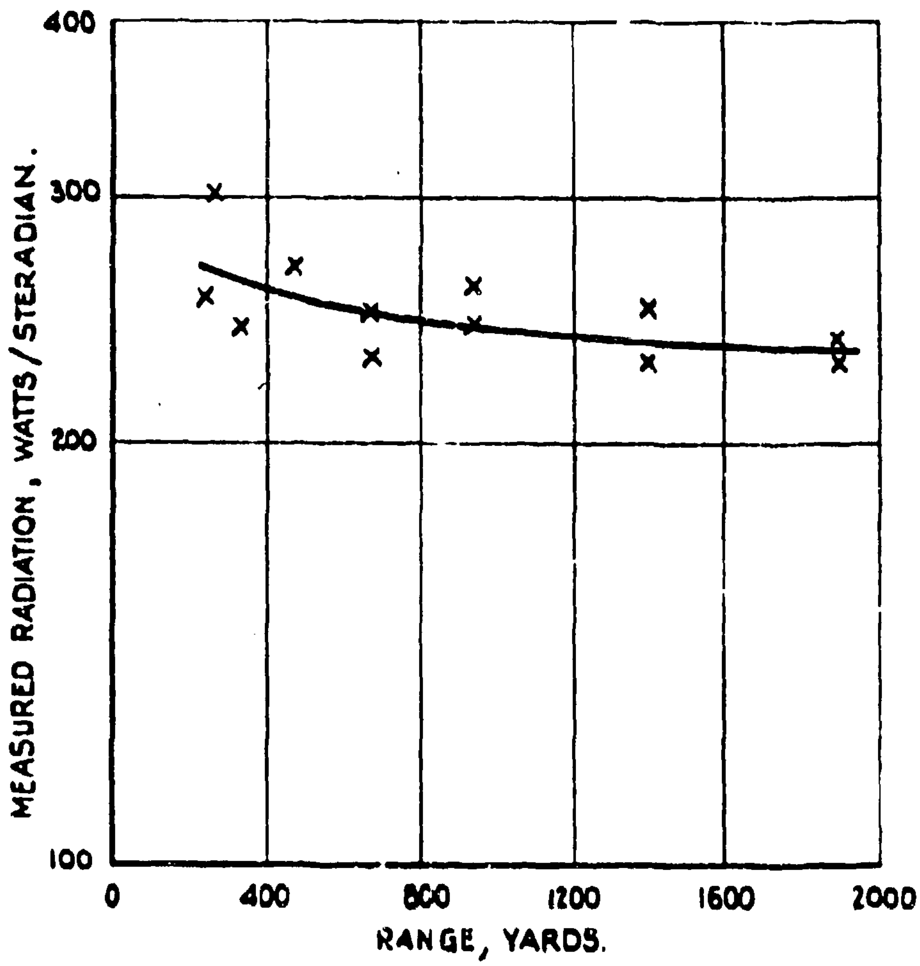

FIG. 2. ATMOSPHERIC TRANSMISSION OF S.R. 580 RADIATION IN PbS. BAND.

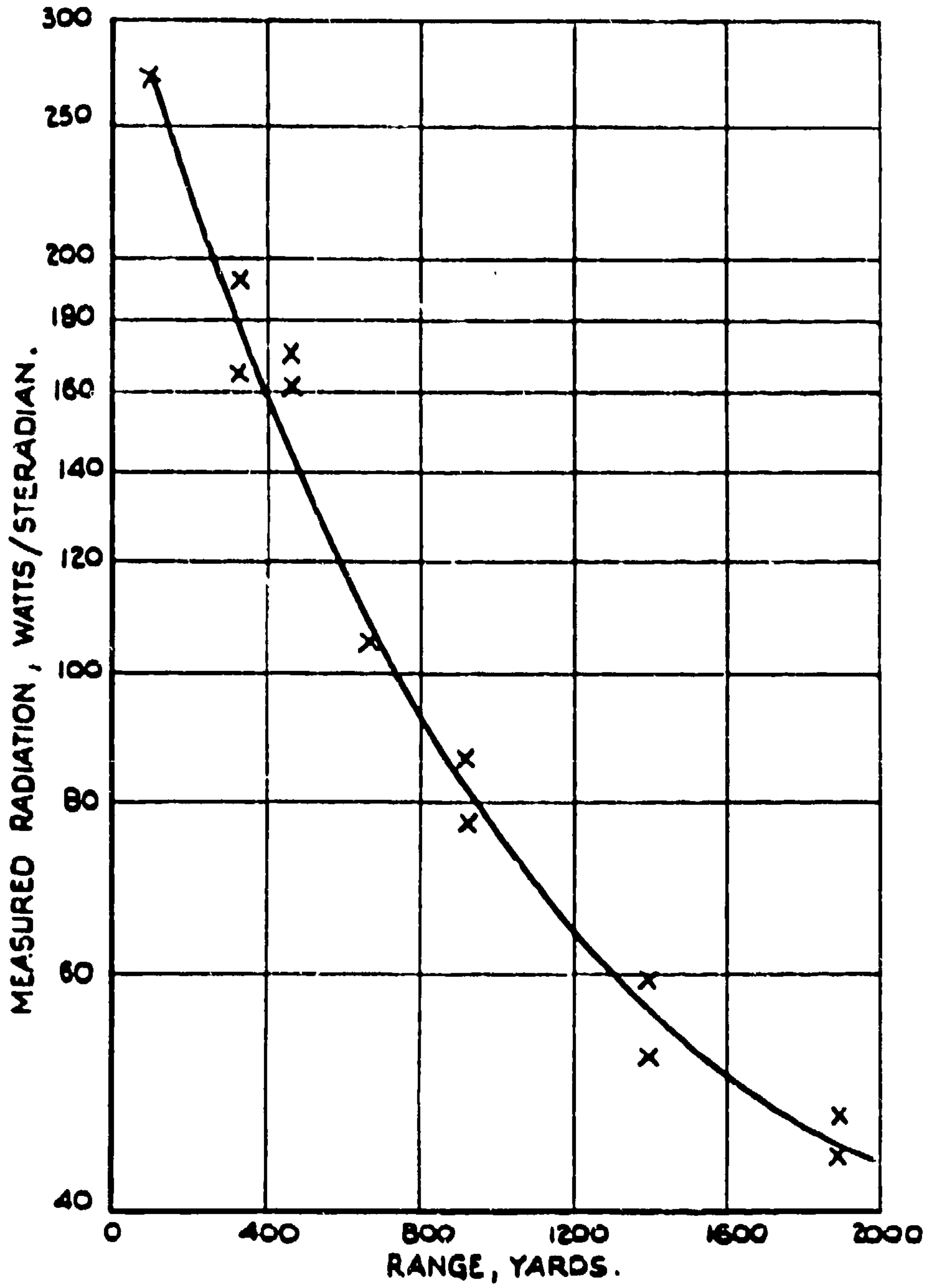

FIG.3. ATMOSPHERIC TRANSMISSION OF SR 580 RADIATION IN PbTe BAND.

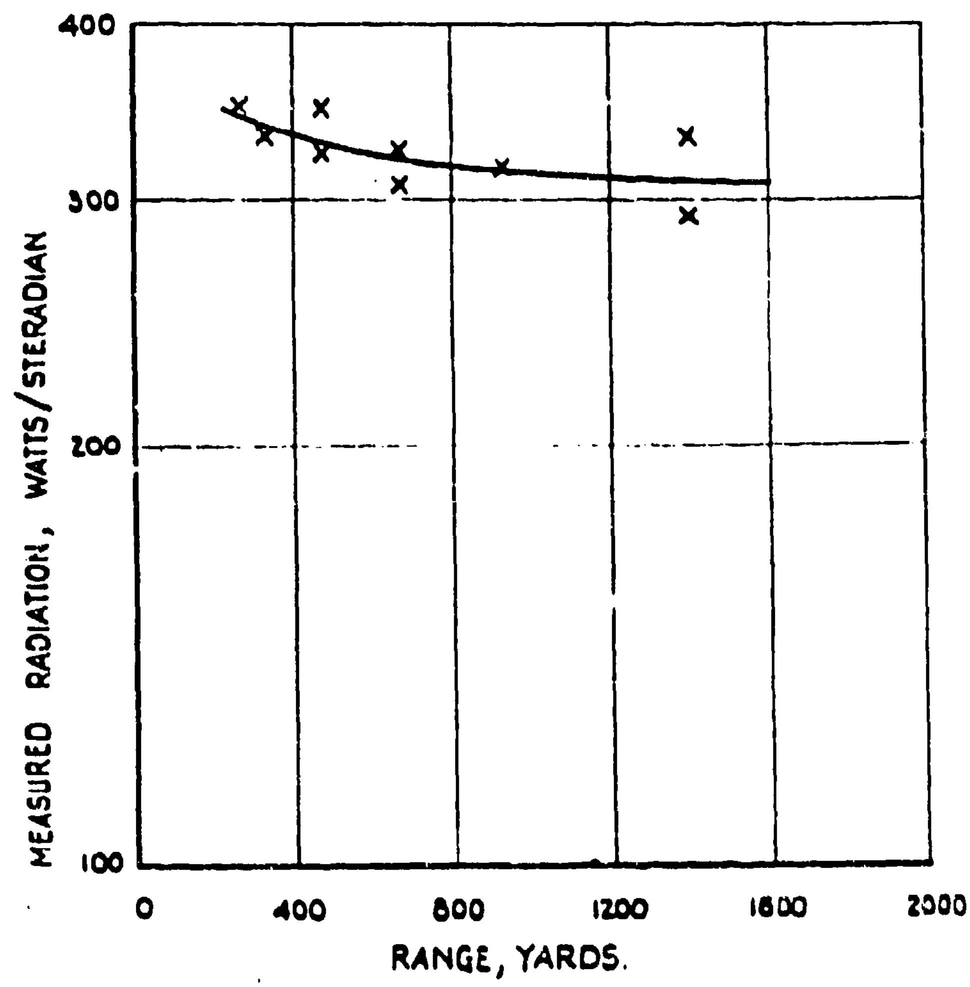

FIG.4. ATMOSPHERIC TRANSMISSION OF SR 107 RADIATION IN PbS. BAND.

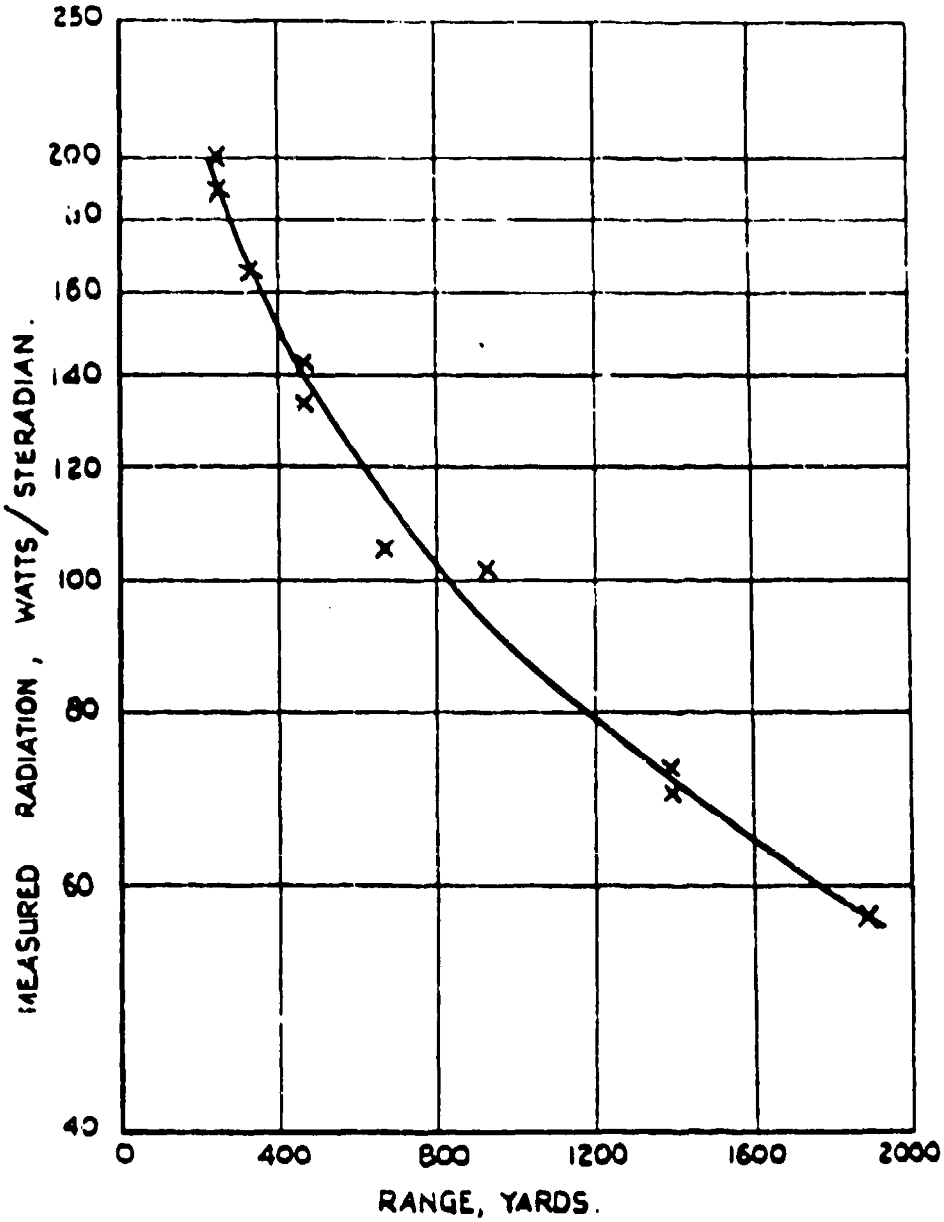

FIG. 5. ATMOSPHERIC TRANSMISSION OF S.R 107 RADIATION IN PbTe BAND.

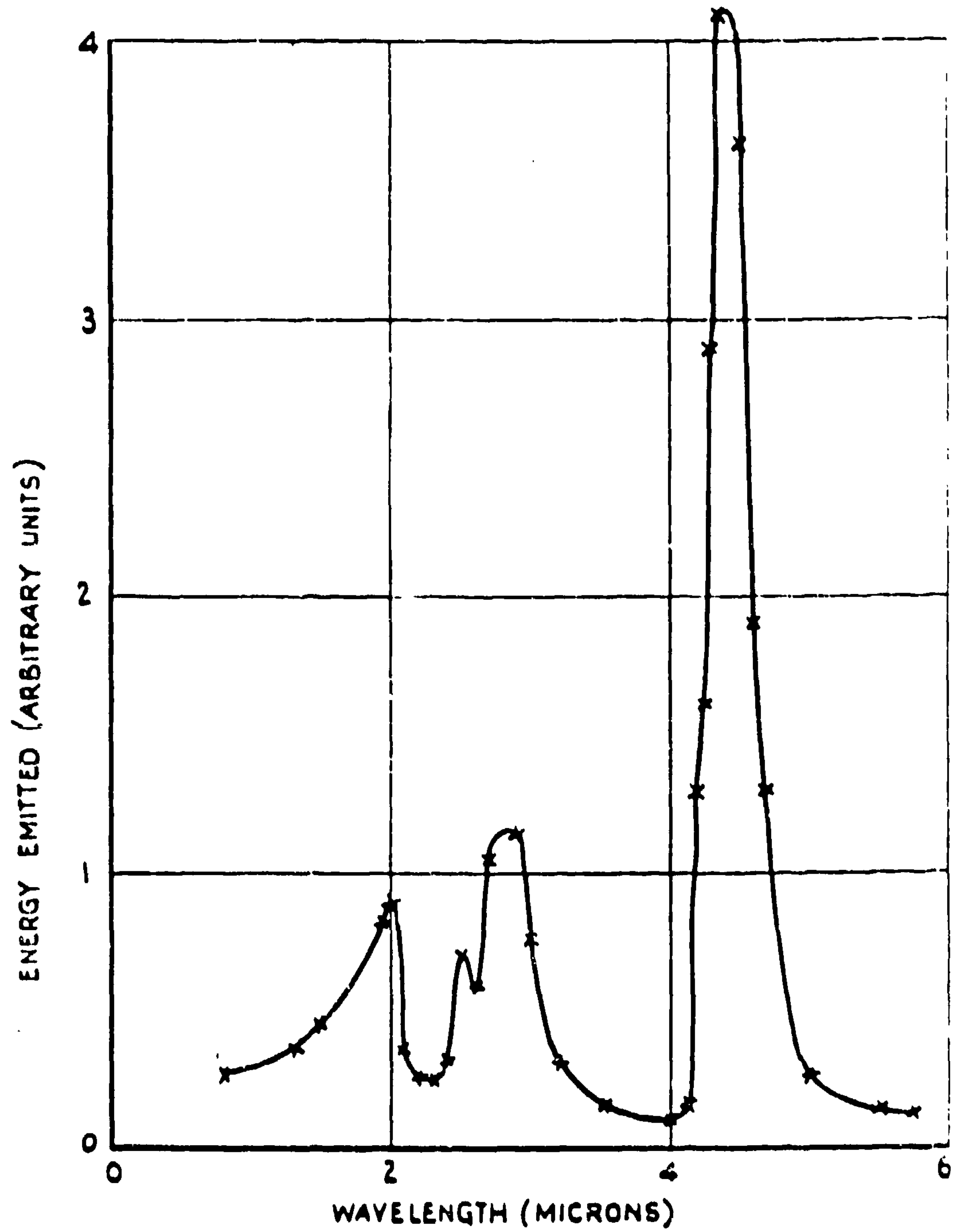

FIG. 6. SPECTRAL EMISSION OF CORDITE (TYPE SC.)

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